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THREE-PHASE POWER DISTURBANCE MONITOR

By

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13 ABSTRACT

This report describes a newly developed three-phase power disturbance monitor which consists of an overvoltage sensor counter, undervoltage sensor counter, low threshold pulse transient sensor counter, high threshold sensor counter and an over-under frequency sensor counter. The monitor will simultaneously monitor voltage or frequency variations and pulse transients of either positive or negative polarity on all phases of a 120/208, three-phase, 50 - 60 hertz power distribution circuit.

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Surges						
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Pulse counters						
Electric power transmission						

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INTRODUCTION

At military installations, anomalies occurring in electrical power systems cause operational malfunctions in and damage to critical loads such as computers and synchronous communication equipments. A need therefore existed for an economical means of monitoring electrical power systems and categorizing the types of anomalies that occur on such systems.

An industry-wide search was conducted to determine if a suitable economical power line monitor was commercially available. Numerous monitors are commercially available, most of which are designed to monitor a specific parameter. Their costs range from approximately $300.00 for strip chart recorders that record either voltage, current, or frequency. This type is capable of recording only one parameter at a time. Such types give very poor response and resolution resulting in questionable data. There are elaborate power line monitoring systems costing as much as $25,000.00 with only a three parameter capability. This led to the NCEL development of a prototype, low cost, three-phase power disturbance monitor which is described in this report.

DESCRIPTION OF MONITOR

The three-phase power disturbance monitor, hereafter referred to as "monitor," shown in Figure 1, is housed in an 22 x 14-3/4 x 10-3/4 inch cabinet. It weighs 48 pounds and has flush mounted handles on each end for ease in handling. The monitor consists of an overvoltage sensor counter, undervoltage sensor counter, over-under frequency sensor counter, low threshold pulse transient sensor counter, high threshold pulse transient sensor counter, a common input voltage section, a common +24 volt DC power supply, visual warning lights, audio alarm and an Ac volt meter. The overvoltage thresholds are adjustable from 120 up to 140 volts RMS. The undervoltage thresholds are adjustable from 115 down to 90 volts RMS. The over-under frequency thresholds are adjustable from 56.5 up to 63.5 hertz. Pulse transient thresholds are adjustable from 50 up to 1200 volts peak to peak. The monitors input power requirements are 120/208 AC, three (3) phase "wye" configuration, 50-60 hertz. Power consumption is approximately 48 watts. The procedures for operating the monitor are presented in the Appendix.

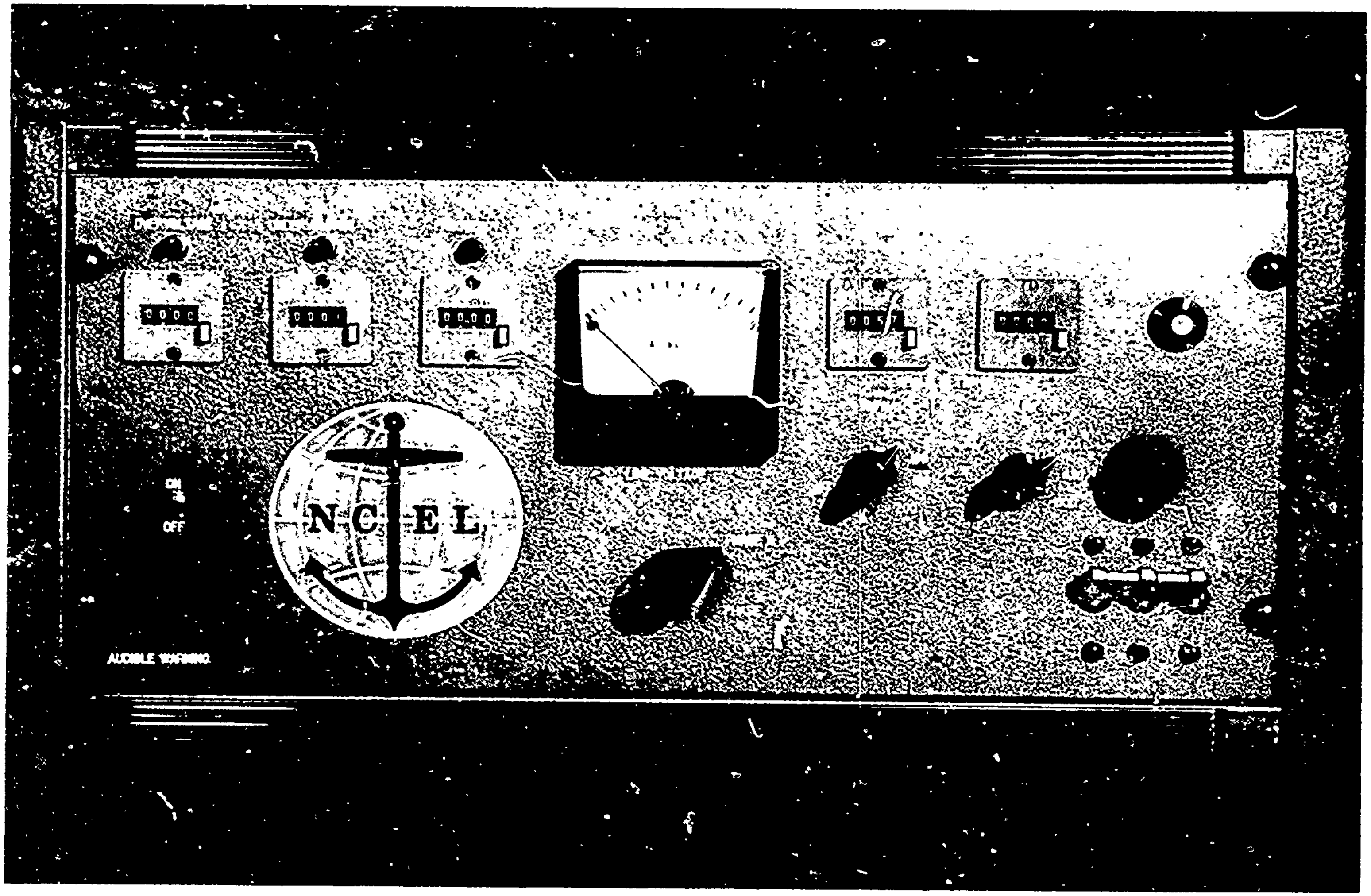


Figure 1. Front panel view of power disturbance monitor.

THEORY OF OPERATION

The overvoltage sensor is a preset threshold sensor. The preset threshold levels are 120, 125, 130, 135 and 140 volts RMS. When a preset threshold level is reached or exceeded simulatneously on all three phases or on any one phase being monitored, the associated counter will count once, the associated warning light will light, and the audio alarm will sound. If the voltage stays at or continues to exceed the preset threshold level setting, the warning light cannot be extinguished, but the audio alarm may be turned off.

The undervoltage sensor is also a preset threshold sensor and can be switched in as desired at preset threshold levels of 115, 110, 105, 100, 95 and 90 volts RMS. When a preset threshold level is reached or exceeded simultaneously on all three phases or any one phase being monitroed, the associated counter will count once, the associated warning light will light and the audio alarm will sound. If the voltage stays at or continues to exceed the preset threshold level setting, the warning light cannot be extinguished, but the audio alarm may be turned off.

The over-under frequency sensor, also of a preset threshold type, has preset levels of 59-61, 58-62 and 57-63 hertz, that can be switched in as desired. If the preset threshold level is reached or exceeded, the associated counter will count once, the associated warning light will light, and the audio alarm will sound. If the frequency stays at or continues to exceed the preset threshold setting, the warning light cannot be extinguished, but the audio alarm may be turned off.

The pulse transient sensors, also of the preset threshold type, can be preset at threshold levels of 50, 100, 150 and 200 volts peak-to-peak. The high level sensor has preset threshold level settings of 300, 450 and 600 volts peak-to-peak. They will sense transients of positive or negative polarity with durations of approximately one (1) microsecond to 16 milliseconds. The electronic circuitry of each is identical. If a pulse transient occurs on any one of the three phases being monitored that reaches or exceeds the preset threshold level setting, the associated counter will count once. No warning light or audio alarm is used with the pulse transient sensors.

The counters are four (4) digit electro-mechanical units with push button reset. The counters, including associated circuits, have a response time between counts of approximately 300 milliseconds.

The audio alarm device is a Sonalert Model SG 628 with a continuous 2500 hertz signal.

CIRCUIT OPERATION

To simplify the description of the circuitry functions in the following discussion, the monitor is divided into the primary power, secondary power, DC power supply, overvoltage sensing and counting, undervoltage sensing and counting, over-under frequency sensing and counting, and low and high pulse sensing and counting. A circuit diagram of the monitor is shown in Figure 2. An inside view of the monitor is shown in Figure 3. A view of a plug board on the extender card is shown in Figure 4.

Primary Power

Primary power is connected to terminal board TB-1. Access to TB-1 is through opening on rear of cabinet. TB-1 has five terminals marked A, B, and C for the phases, N for neutral, and GRD for ground. Power from TB-1 is connected to S-1 which is a three-phase, two amp switch breaker. The main power on indicating light is connected to Phase A after S-1. A front panel mounted 0-150 volt AC meter can be switched to any of the three phases to measure the input line voltage. The input power from S-1 is connected to the primaries (120 volt RMS) of three transformers, T-1, T-2, and T-3, wired for a three-phase "wye" configuration. This primary power is the power that is monitored.

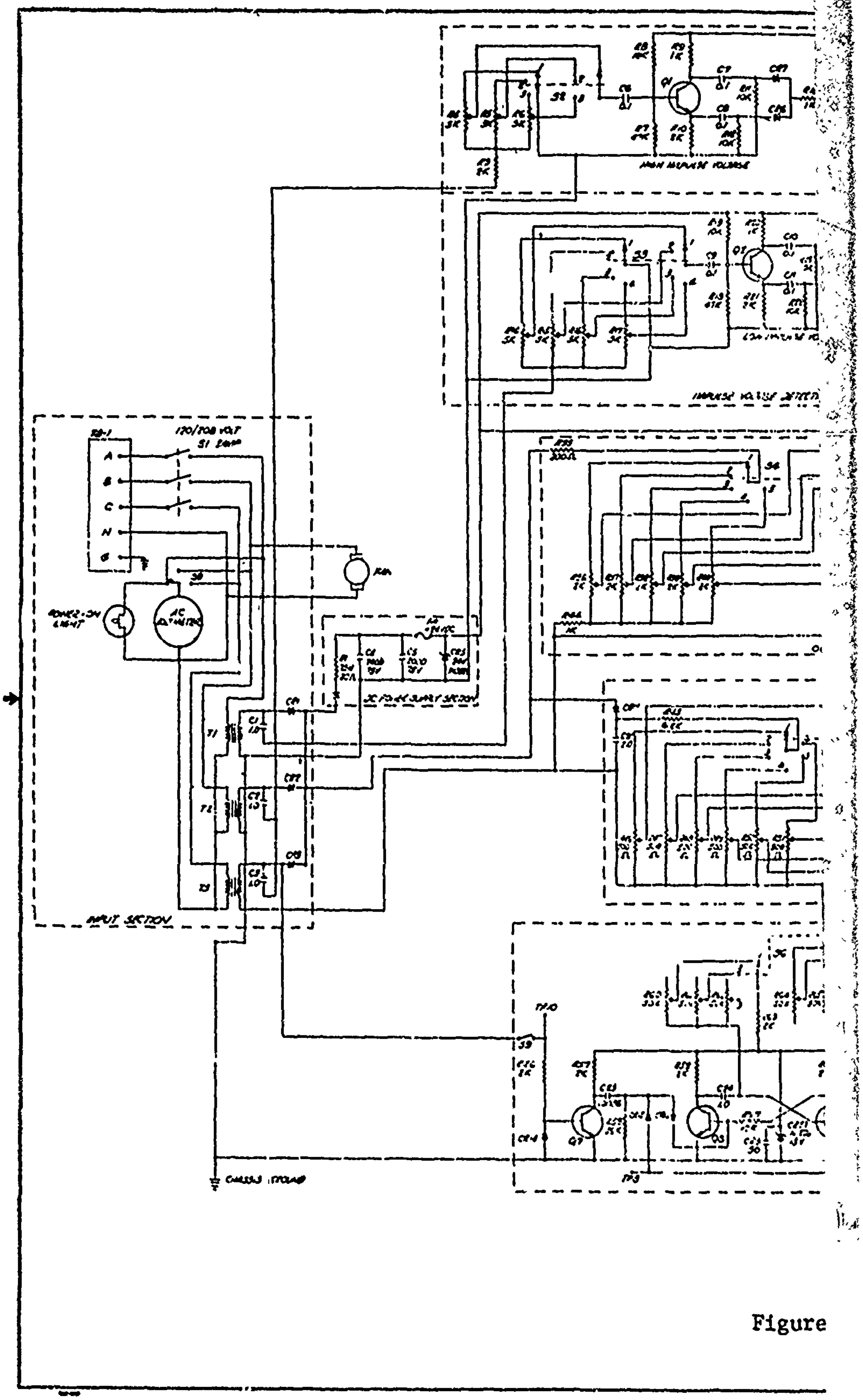
Secondary Power

Secondary power from T-1, T-2, and T-3 is 30 volt RMS. This voltage is rectified by diodes CR-1, CR-2, and CR-3. Figure 5 shows the voltage waveshape of this three-phase rectified voltage. This rectified voltage is the voltage that is sensed for over and under voltage conditions.

DC Power Supply

The DC power supply consists of isolation diode CR 4, current limiting resistor R-1, filter capacitors C-4 and C-5, 1 amp fuse F-1 and voltage regulating (24 volt DC) zener diode CR 5. The output is 24 volt DC regulated and is used to pow the monitor.

A

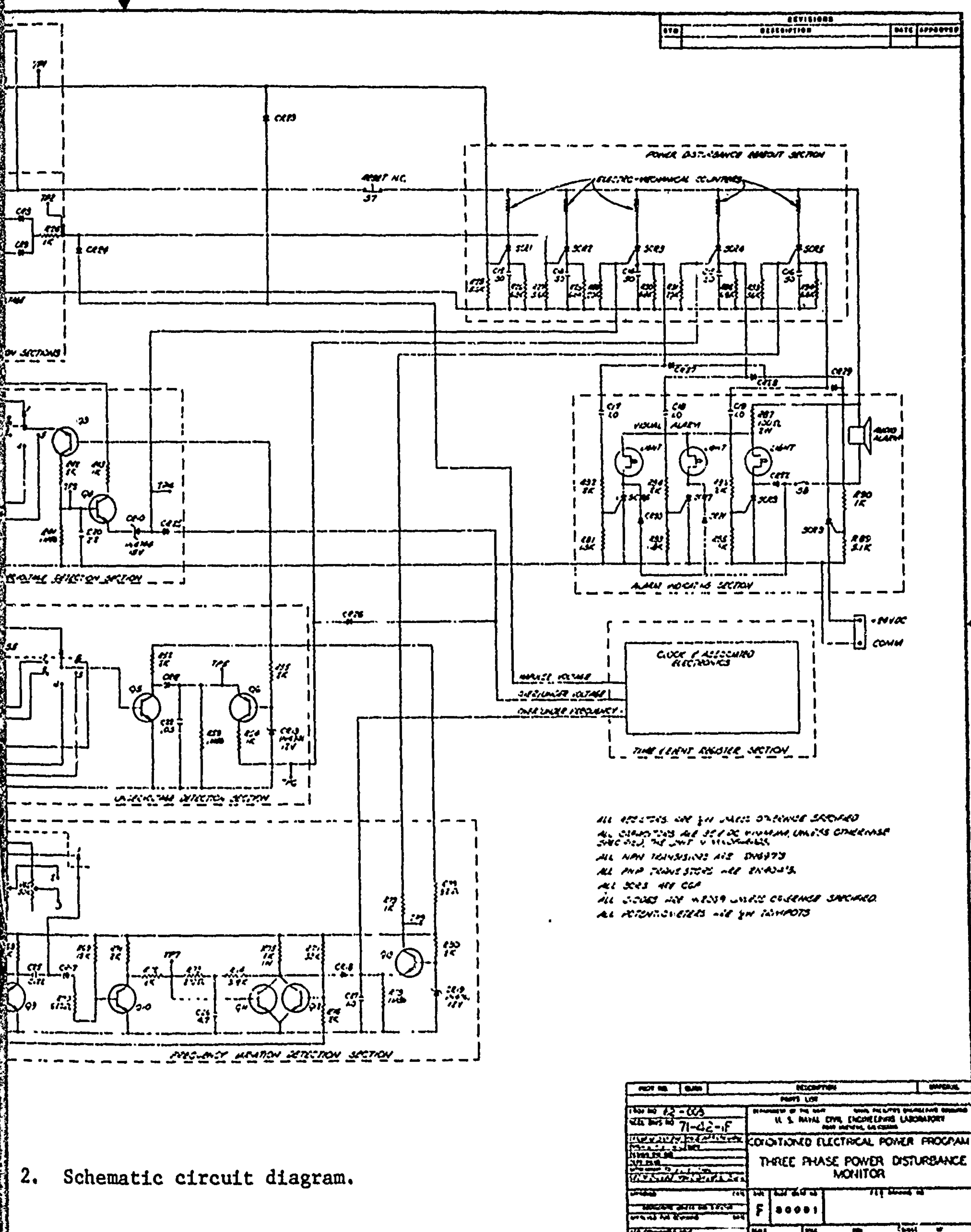


120/208 VOLT
S1 2 AMP
A
B
C
N
G
POWER-ON LIGHT
AC VOLTMETER
FAN
T1
T2
T3
INPUT SECTION
DC POWER SUPPLY SECTION
HIGH IMPULSE VOLTAGE
CHASSIS GROUND

Figure

5 + 6

B



2. Schematic circuit diagram.

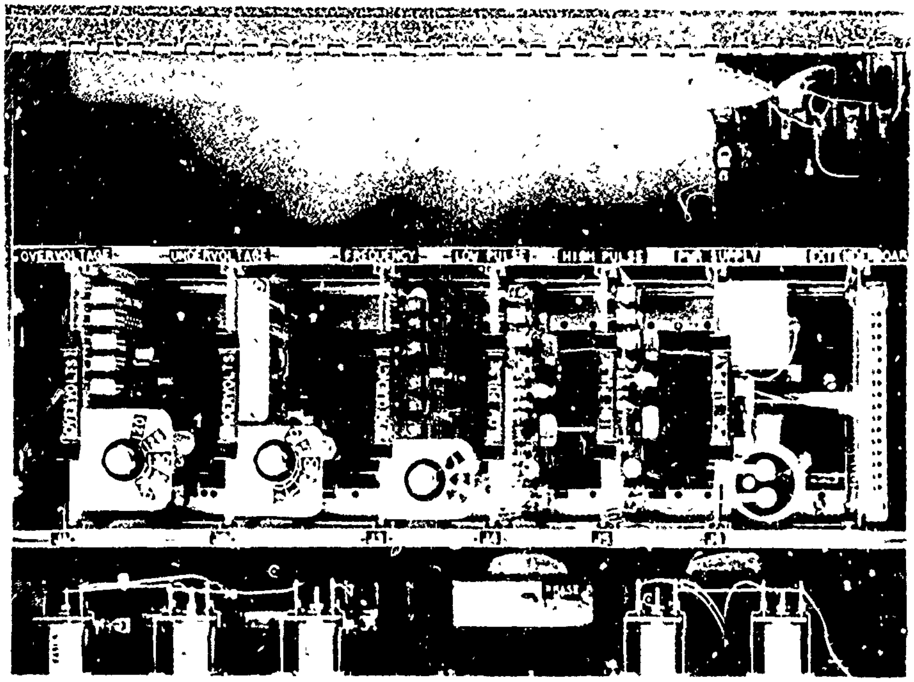


Figure 3. Inside view of monitor looking down at the top.

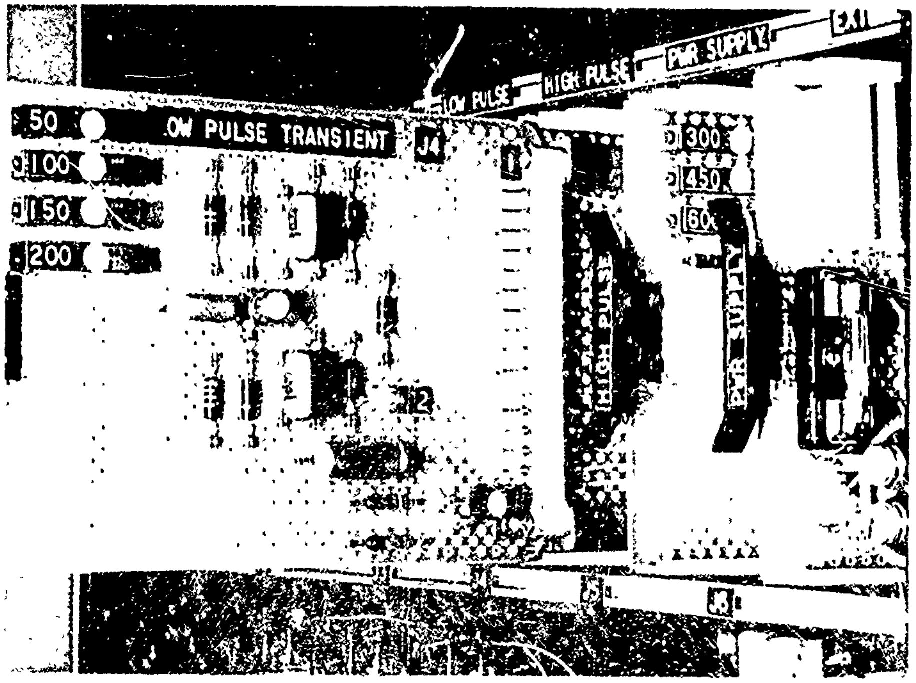


Figure 4. A view of a plugboard on extender board.

Overvoltage Sensing and Counting Circuitry

The input signal to the overvoltage sensor is the three-phase rectified voltage. An input attenuator network consisting of R-36, 37, 38, 39, 40 and 44 is used to preset the threshold levels of the overvoltage sensor. Q-3 is normally in a cut-off state. An increase in line voltage causes the rectified voltage at the emitter of Q-3 to increase. When this voltage exceeds the voltage at the base of Q-3, it starts to conduct. As Q-3 conducts, C-20, which is connected to the base of Q-4, starts to charge positively. If the rectified line voltage continues to increase, this increases the conduction of Q-3 and charges C-20 to a more positive voltage. C-20 performs as a filter so short duration positive pulses do not cause the overvoltage counter to count. When this voltage exceeds 15 volts (the breakdown voltage of CR-10), Q-4, which is normally cut off, starts to conduct. Figure 6 shows the voltage waveshapes at TP-4 with the threshold level setting exceeded. This conduction causes a positive voltage on the gate of SCR-3 causing it to turn on. This allows C-14 to rapidly charge. As the charging current passes through the coil of the overvoltage electro-mechanical counter, it advances one count. Simultaneously, as C-14 charges C-17 also charges putting a positive voltage on the gate of SCR-6 which turns it on. This grounds one side of the overvoltage warning light and audio alarm turning them on. If the line voltage remains above the preset threshold level setting, Q-3 and Q-4 will continue conducting keeping a positive voltage on the gate of SCR-3, keeping it turned on. If the reset button is depressed, the warning light will turn off and the audio sound will stop, but when the reset button is released, the warning light will light and the sound will continue. The sound can be turned off by S-8 but the warning light will remain lighted as long as the line voltage remains above the preset level setting. When the line voltage drops below the preset threshold level setting, Q-3 and Q-4 stop conducting; this removes the positive voltage from the gate of SCR-3. With the gate no longer positive and C-14 fully charged, SCR-3 turns off. Then C-14 discharges through R-30 resetting it for the next count. Now the warning light may be extinguished by depressing the reset button.

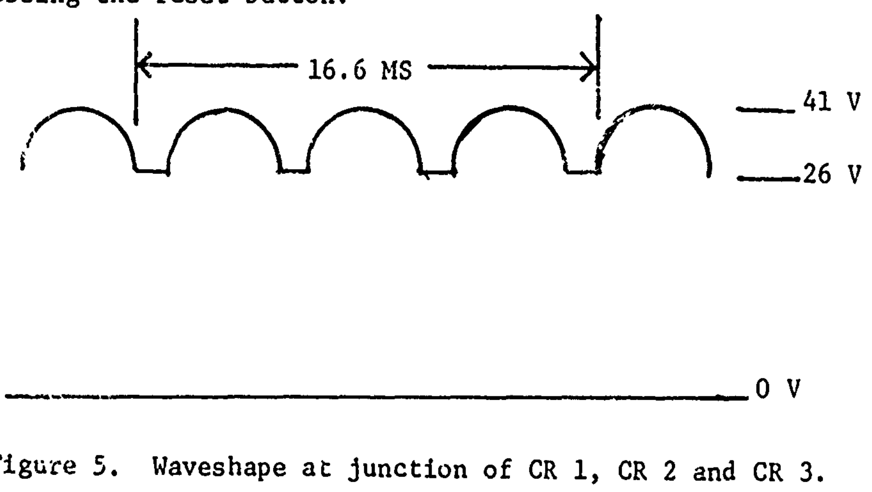


Figure 5. Waveshape at junction of CR 1, CR 2 and CR 3.

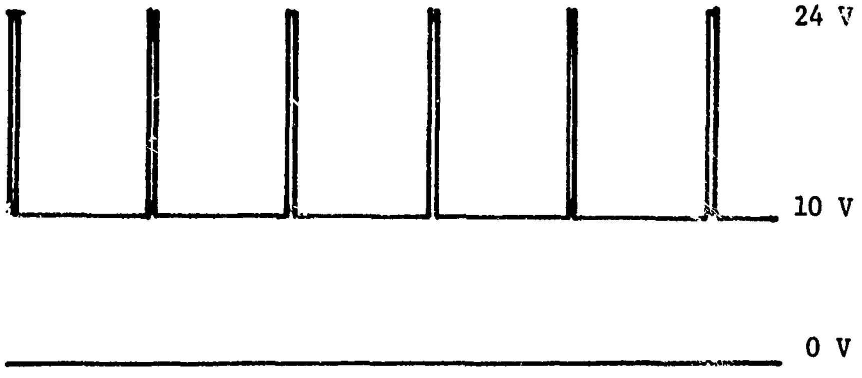


Figure 6. Waveshape at TP-4 with preset threshold exceeded.

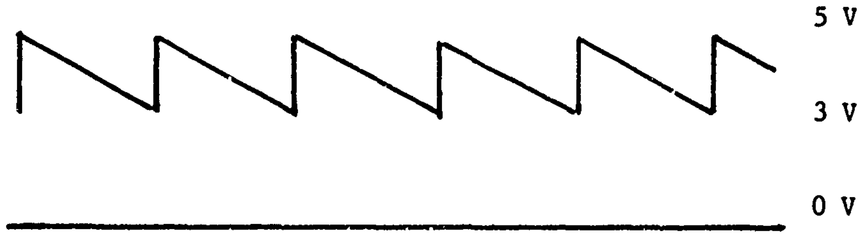


Figure 7. Waveshape at TP-5 with threshold exceeded.

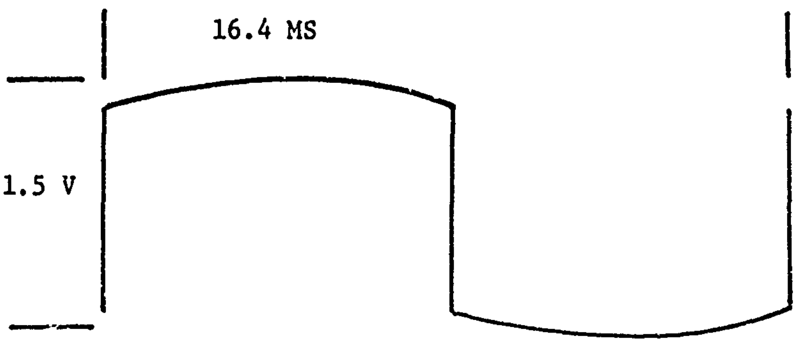


Figure 8. Waveshape at base of Q-7

Undervoltage Sensing and Counting Circuit

The input to the undervoltage sensor is the three phase rectified line voltage. This is fed through isolation diode CR-11 then is partially filtered by C-21. An input attenuation network consisting of R-45 through R-51 is used to preset the threshold levels of the sensor. Q-5 is normally biased to almost full conduction by the voltage from the input attenuator that is applied to its base. When the line voltage decreases, the voltage on the base of Q-5 decreases. This decreases conduction through Q-5 causing the collector voltage to increase. As the collector voltage increases, the charge on C-22 increases which is attached to the emitter of Q-6. C-22 performs as a filter so that short duration negative transients can not cause the undervoltage counter to count. When this charge exceeds 5.6 volts, Q-6 starts to conduct. As the line voltage reaches or exceeds the threshold level setting, Q-6's conduction puts a positive voltage on the gate of SCR 4 thus turning on SCR 4. The operation and circuitry of the counting and warning circuits of the over- and undervoltage sections are identical. Figure 7 shows the voltage waveshpae at TP-5 with the threshold setting exceeded.

Over-Under Frequency Sensing and Counting Circuit

The input to the over-under frequency sensor is from the secondary of T-3. R-56 and CR-4 are used as the input attenuators. Figure 8 Shows waveshape at the base of Q-7. The output of Q-7 is a positive 18 volt square wave. Figure 9 shows waveshape on collector of Q-7. This square wave is differentiated by C-23 and R-58. Figure 10 shows this waveshape. The positive going pulse on the differentiated waveshape goes to the base of Q-8 through CR-16. The negative going pulse goes to the base of Q-12 through CR-15 and R-76. Q-8, Q-9 and associated circuitry are a multivibrator that is triggered by the positive pulse at the base of Q-8. The output of the multivibrator is a positive square wave. The on time of this multivibrator is controlled by the settings of R-60, 61, or 62. This on time setting is the overfrequency threshold level setting. Figure 11 shows wave shape at the collector of Q-9. The output square wave of the multivibrator is differentiated by C-25 and R-64, 65 or 66. The negative pulse is coupled to the base of Q-10 through CR-17 and R-70. Q-10 inverts and amplifies this pulse which results in a positive square wave on the collector. The width of this square wave is controlled by the settings of R-64, 65 or 66. This is the underfrequency threshold setting. This positive square wave is coupled to the base of Q-11 through R-72. Q-11 and Q-12 have a common connection for their collectors and a common connection for their emitters. Both Q-11 and Q-12 are biased to almost full saturation. This drives their common collector voltage to approximately zero. Simultaneously, Q-11 has a positive square wave on its base and Q-12 has a negative pulse on its base. Figure 12 shows these wave shapes. As long as the positive

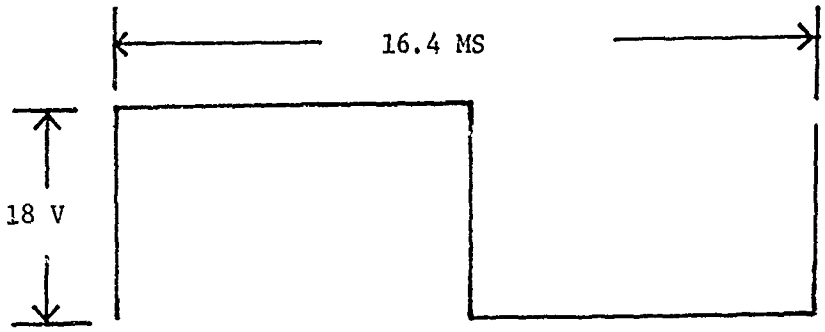


Figure 9. Waveshape at collector of Q-7.

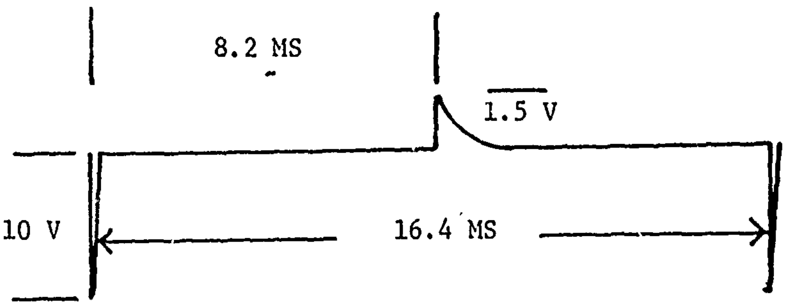


Figure 10. Waveshape at junction of C-23 and R-58

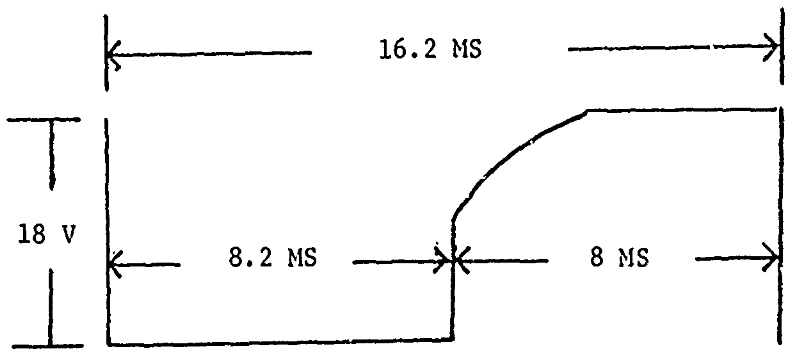


Figure 11. Waveshape at collector of Q-9.

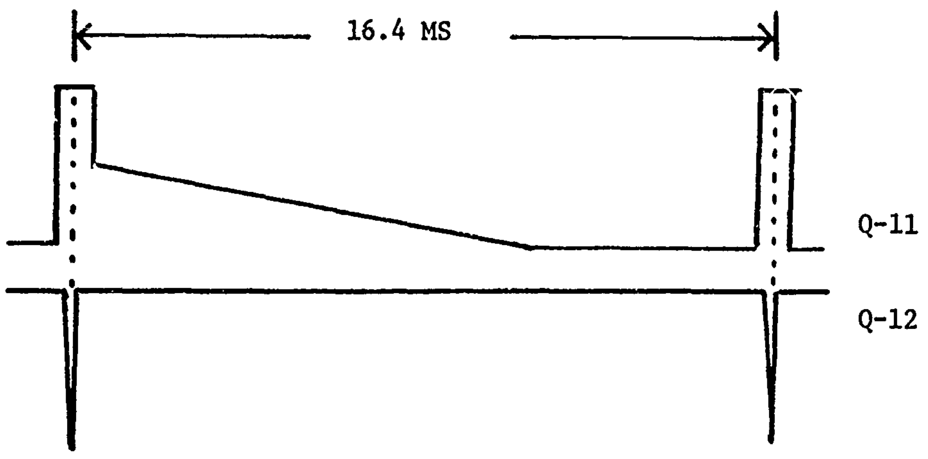


Figure 12. Waveshape at base of Q-11 and Q-12.

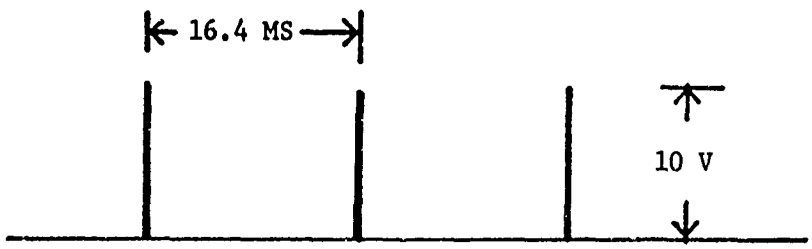


Figure 13. Waveshape at TP-9 when frequency threshold is exceeded.

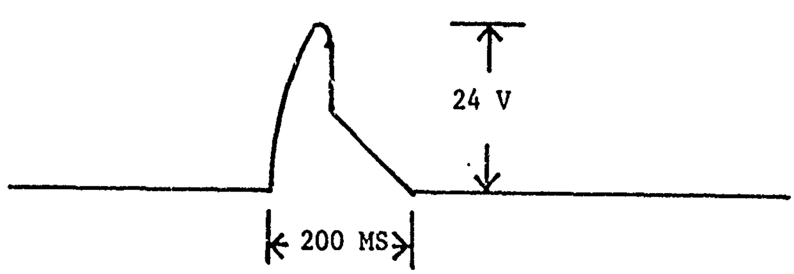


Figure 14. Waveshape at TP-1 or TP-2 when pulse transient detected.

square wave and negative pulse are in coincidence, no signal will appear on the common collector point of Q-11 and Q-12, thus indicating the frequency has not exceeded the preset threshold level setting. When the preset threshold level setting is reached or exceeded, a 14 volt positive pulse will appear on the common collector point of Q-11 and Q-12. These pulses are coupled through CR-18 causing C-27, which is connected to the base of Q-13, to charge in a positive direction, when this charge reaches 12 volts, Q-13 starts to conduct. Q-13 is normally held in a cut-off state, by the positive 12 volts maintained on its base by zener CR-19. As Q-13 conducts, this puts a positive voltage on the gate of SCR 5, turning it on. The counting and warning circuits of the over-underfrequency function as the counting and warning of the over and under-voltage circuits. Figure 13 shows the wave shape at TP-9 when the over-underfrequency threshold level setting has been exceeded.

Pulse Sensing and Counting Circuits

The input to the pulse sensors is through coupling capacitors C-1, C-2, C-3 and a resistive attenuator network consisiting of potentiometers. The potentiometers are used to set the preset threshold level settings of the sensors. The pulse signals are coupled through C-6 or C-9 to the base of Q-1 or Q-2. C-1, C-2, C-3, the potentiometer and C-6 and C-9 also filter the voltage sine wave to almost a zero potential. Q-1 and Q-2 are biased class "A", so they will conduct with positive or negative pulse transients. Q-1 and Q-2 with the associated components act as a phase splitter network so that any transient that is detected will appear as a positive pulse at TP-1 or TP-2. This pulse will also appear on the gate of SCR 1 or SCR 2, turning it on and causing the counter to advance once. The counting circuits operate as described in the overvoltage section. No visual or audible alarm is used. Figure 14 shows the wave shape that will appear at TP-1 or TP-2 when a transient that exceeds the preset threshold level is detected.

OPTIONAL FEATURES

The following optional features may be incorporated in the monitor:

Time and Event Register

To correlate power disturbances with equipment operational failure and physical damage, the time and event feature is needed. Time can be separated into month, day, hour, minute and even seconds, if that accuracy is necessary. The events can be registered with the time, thus indicating exactly what and when a specific power anomaly occurred.

External Alarm Voltage Terminal

An external voltage feature would have the capability of triggering a remote alarm system, powering down critical equipment and initiate the switching of critical loads to another power source.

Multiple Voltage Power Input Connector

A primary input multiple voltage connector such as an attenuator network or multi-tap transformer would enable the monitors use to the primary side of substations with voltages of 4160 and even greater.

Over-Under Frequency Register

Over- and underfrequency register would give the capability of determining whether an increase or decrease from the base frequency is a cause of equipment operational failure or damage.

Single-to-Three Phase Switching

An internal switching section that would allow the three-phase monitor to be utilized as a single phase monitor would greatly improve the versitility of the unit.

FINDINGS

1. Extensive testing of the monitor using the NCEL power system synthesizer as the transient source has demonstrated that the monitor accurately detects all voltage and frequency deviations and pulse transients that might appear on a power system.

2. A six (6) week continual monitoring period shows that the monitor can operate unattended without operational failures with all preset threshold level settings remaining constant.

CONCLUSIONS

1. Wherever electrical power is suspect as the cause of equipment operational failures or damage, the monitor is a useful instrument for verifying the quality of power supplied to such equipment.

2. When critical equipment must operate within close voltage and frequency tolerances, the monitor can act as a warning device when any of the tolerances are exceeded.

Appendix A

OPERATIONAL PROCEDURES

1. Connect the monitor to a three-phase, 120/208 "wye" source. When connection is made at TB-1, proper phase sequence should be used.

2. Set the threshold level settings to the levels desired by turning the associated knobs to the levels required. The pulse transient level knobs are located on the front panel. The over-voltage, undervoltage and over-underfrequency knobs are located on their associated plug board. Access to these is through the top cover.

3. Put the main power switch located on the front panel, to the "on" position. The main power indicating light should light. Then check to make sure all three phase voltages are present by switching the panel meter swtich to each of its positions and observe the voltage indicated on the meter.

4. If one or all of the visual warning lights light, momentarily press the reset button located on the front panel. This should turn off the visual warning lights and the audio sound if all three phase voltages and frequencies do not exceed any of the preset threshold level settings.

5. Reset all of the electro-mechanical counters to zero by pushing the reset button located on the front of each counter.

6. The audible alarm may be used by turning its on-off switch located on the front panel to the on position.